

Fiber-Reinforced Concrete for Bridge Structures

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Outline

- Goal: longevity
- Deterioration mechanisms
- Protective measures
- Fiber-reinforced concrete (FRC)
- Field Applications of FRC
- Conclusions



Goal is Longevity! Build to Last!

Innovations in concretes and reinforcement have enabled:

- Improved durability
- Low environmental impact
- Cost-effectiveness
- Minimal inconvenience to traveling public
- Improved safety



Pantheon



CONCRETE IS DURABLE!

Roman concrete, 2,000 years old!



Year 1,002,019



Design and Build it right! Keep it dry!



Infiltration into Concrete

- Deterioration because of water and solutions penetrating through poor quality concrete and cracks:
 - Freezing and thawing
 - Alkali-aggregate reactions
 - Sulfate attack
 - Corrosion: if reinforced



Freezing and Thawing Damage



Saturated, non-air entrained



Alkali-Silica Reactions



Water is necessary.



Sulfate Attack



Sulfate solution penetration



Corrosion

- Corrosion is a major distress in reinforced concrete structures exposed to the environment.



Improvements in Concrete

- Low Permeability
 - Supplementary cementitious material (SCM)
 - Low water-cementitious materials ratio
- Low shrinkage
 - Low paste content, shrinkage reducing admixture (SRA)
- Crack resistant: (reduce amount and width)
 - Fibers
- Abrasion resistant
- Good construction practices
 - Proper consolidation and curing



Improvements in Reinforcement

- Corrosion-resistant conventional reinforcement
 - Stainless steel (SS), MMFX2, etc.



- Corrosion-resistant and corrosion-free prestressed reinforcement
 - Carbon Fiber Reinforced Polymer (CFRP) and SS



CFRP Reinforcement



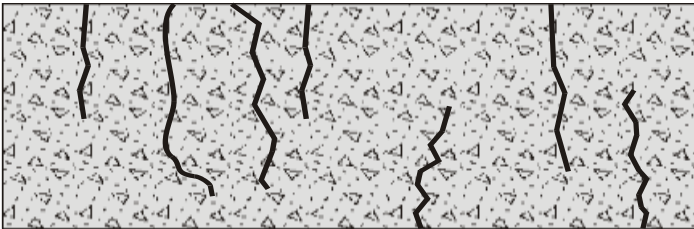
CFRP is corrosion-free.



Cracks

There are two kinds of concrete:

- One cracked
- One about to crack



Charlie Robson

Former VDOT State Materials Engineer



Cracks

- Occur when tensile stresses exceed the tensile strength of concrete
- Causes:
 - Volumetric changes: moisture and temperature
 - Chemical reactions
 - Loading



Crack Control – FRC

- Synthetic fibers in low amounts, 1.5 lb/yd³ (0.1%) are used to minimize plastic shrinkage.
- Larger amounts of fibers up to 2% needed for crack control in hardened concrete. The goal is to keep crack width less than 0.1 mm. Such tight cracks resist infiltration of water and solutions.

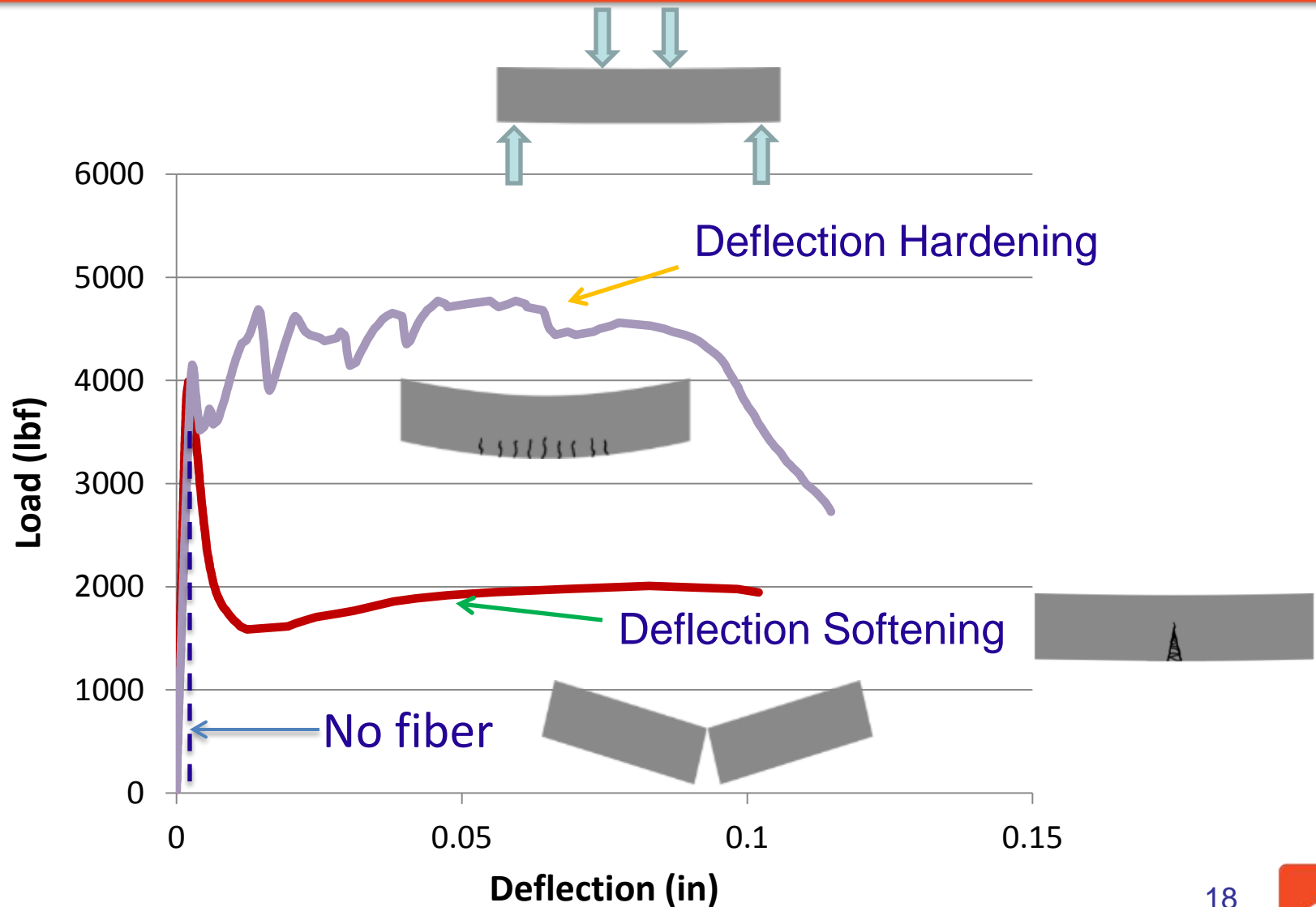


Crack Control – FRC

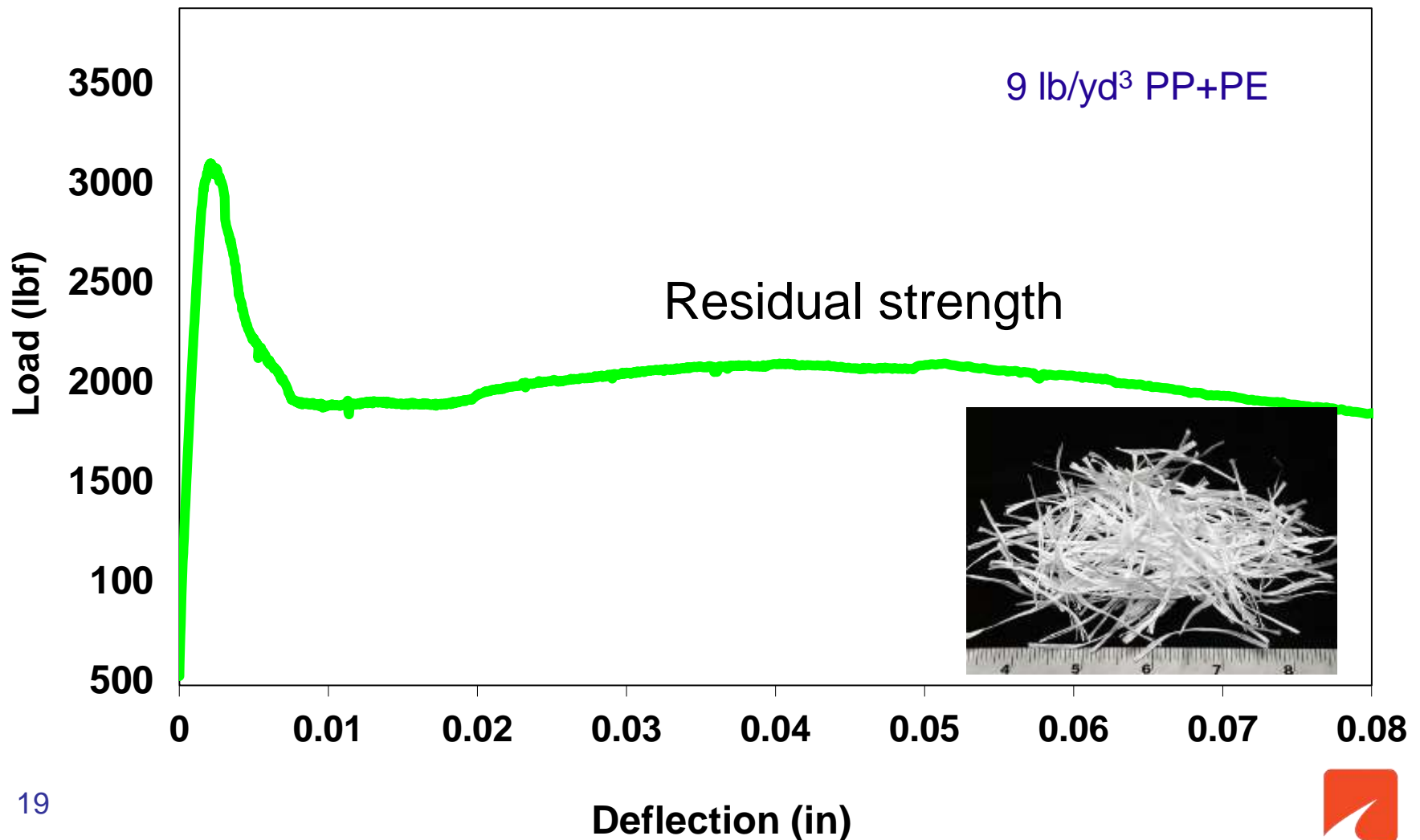
- FRC: fiber-reinforced concrete
 - Improve tensile strength
 - Increase ductility
 - Control cracking
- Special FRC
 - ECC: engineered cementitious composite
 - VHPC: very high-performance concrete
 - UHPC: ultra high-performance concrete



Flexural Test - FRC



Early Work with FRC - Lexington



Lexington – FRC 2000



Lexington Crack Survey - FRC

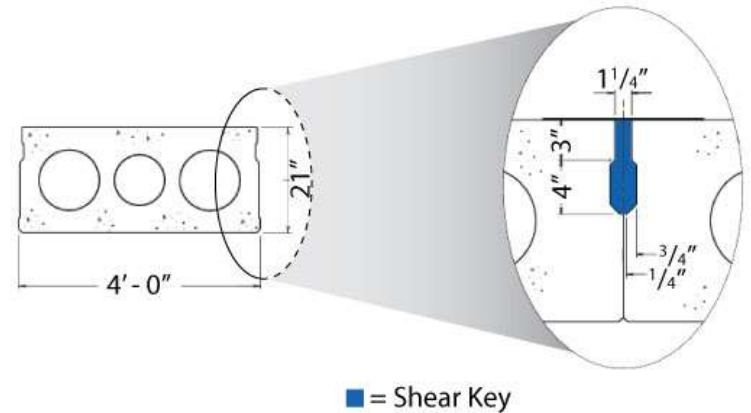
Crack	Control	Fiber
Total Length (ft)	151	59
Average Width (mm)	0.53	0.29

After 5 years



ECC – 2013 on

- Shear Keys
 - Winchester
 - Surry
- Closure Pours
 - I-64 Bridge over Dunlap Creek
- Culvert Repair



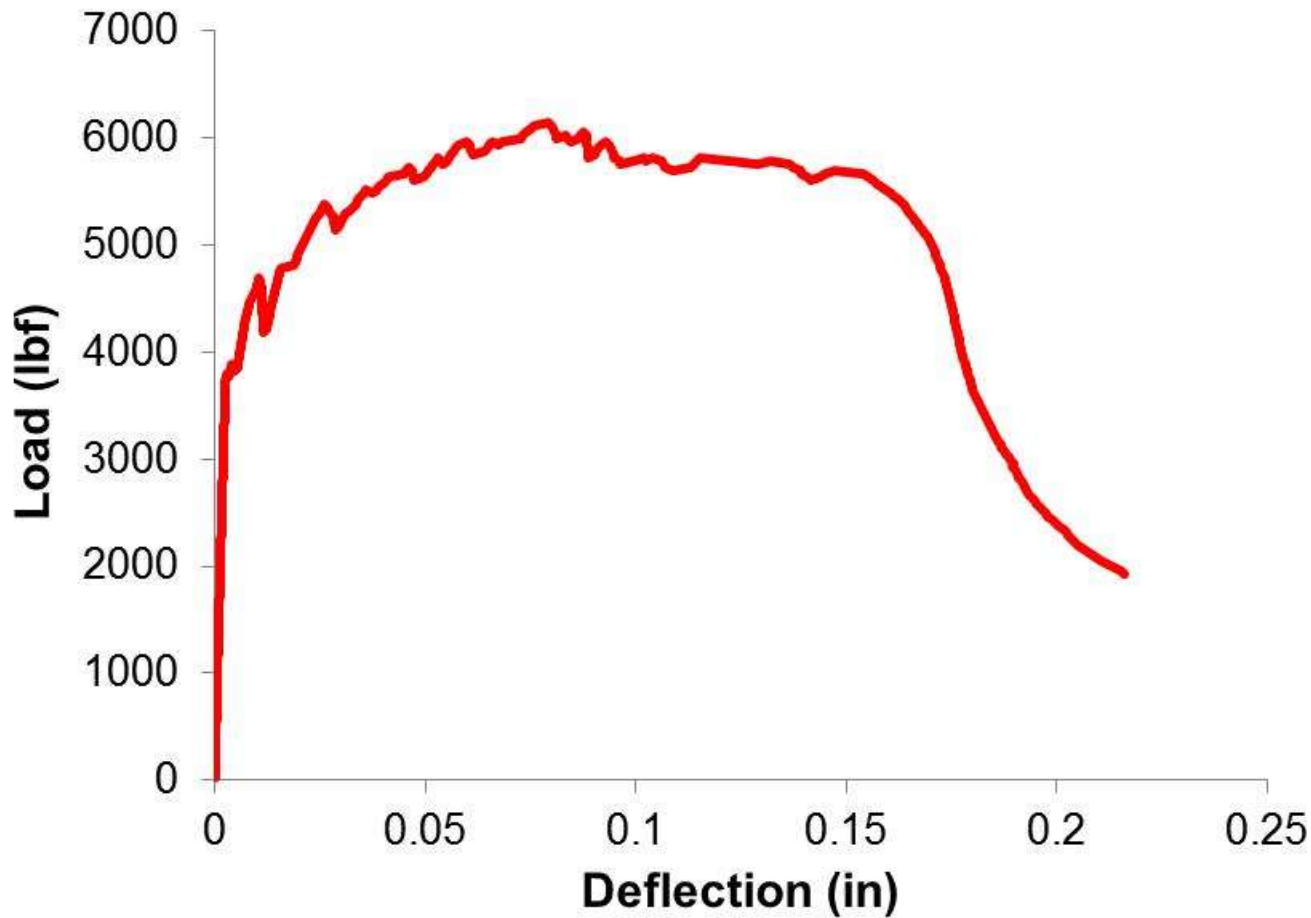
7-d comp str > 4,000 psi



PVA



ECC Mixtures

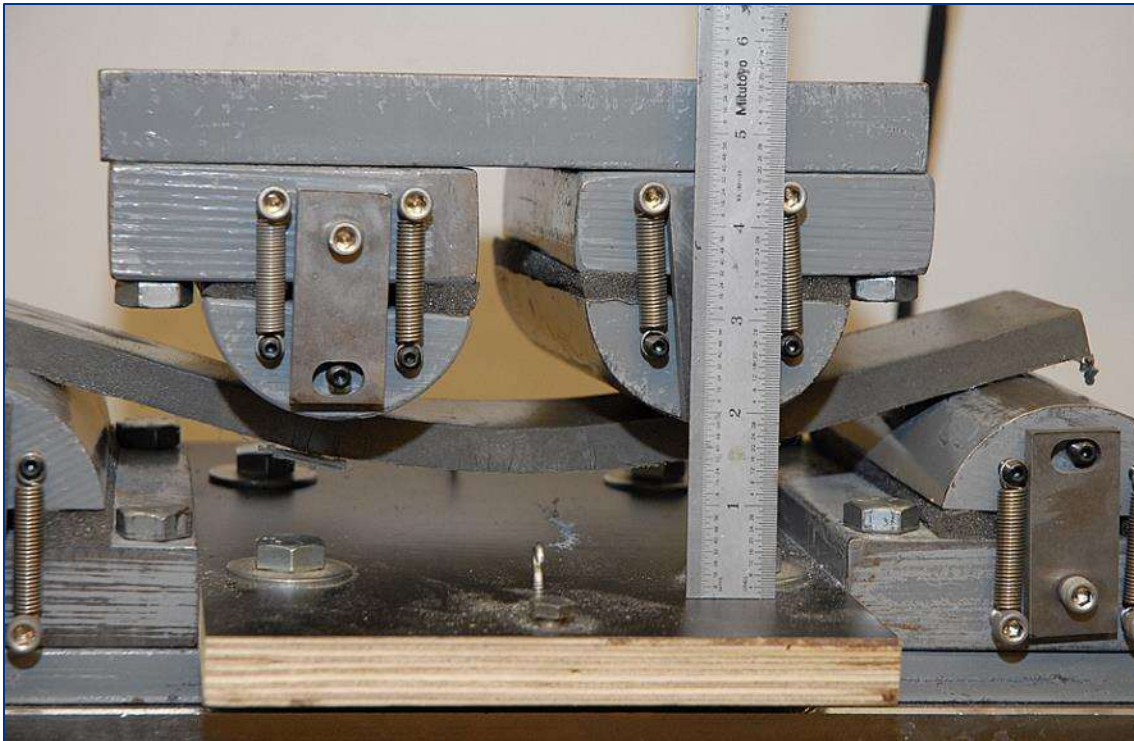


First crack flexural strength at 7 days: 667 psi
Max flexural strength at 7 days: 1,140 psi



ECC

- Bendable concrete, tight cracks <0.1 mm



ECC

Deflection



Tight cracks
(<0.1 mm)



Route 645 Bridge: Shear Keys ECC



Route 645 - Shear Keys - 2013

Non-shrink grout



UHPC



ECC with PVA fibers



After 3 months, only ECC did not leak

ECC – Culvert Repairs – 2017, 2018



Trailer Pump



Finished Repair with ECC



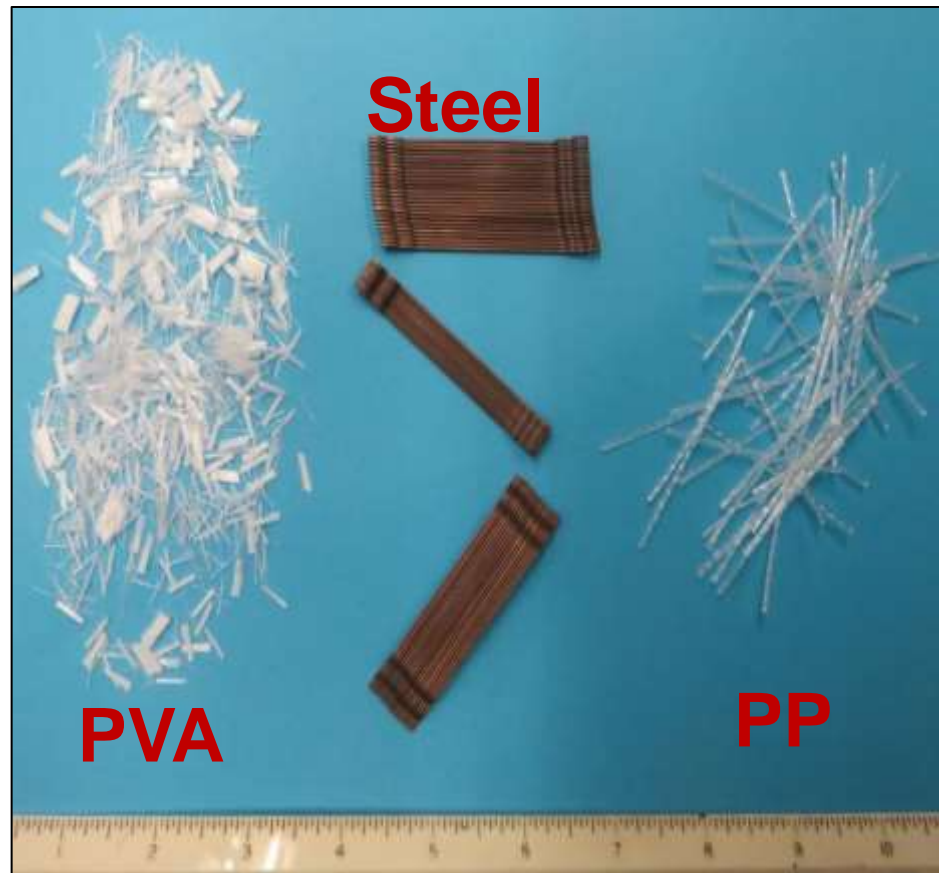
I-64 Dunlap Creek Bridges: 2014, 2015



Link Slab (Closure Pour)



Fiber Reinforcements – I-64



Tight Cracks



VHPC work at Bristol - 2018

- The mix had high flow rates but was sticky



VHPC in Block-outs



28-d compressive strength \geq 11,500 psi



VHPC work at Sperryville - 2019



VHPC work at Sperryville - 2019



UHPC - Route 624 - 2007



28-d compressive strength $\geq 30,000$ psi
with steam curing



UHPC - Steel Fibers



Brass coated steel fibers;
 $L = 14 \text{ mm}$, diameter = 0.185 mm



UHPC Mixture



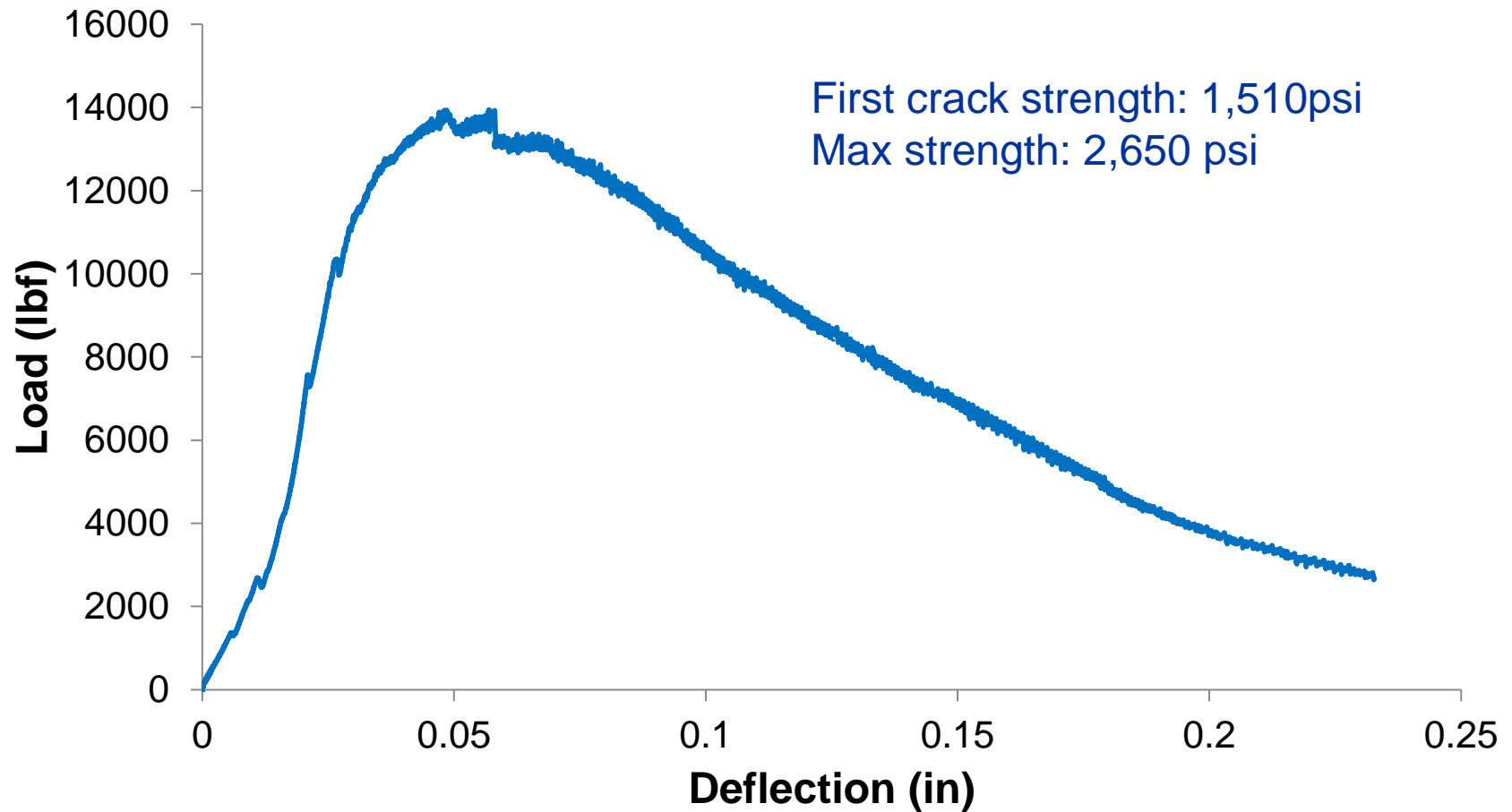
UHPC Beams



Plant had twin shaft mixer



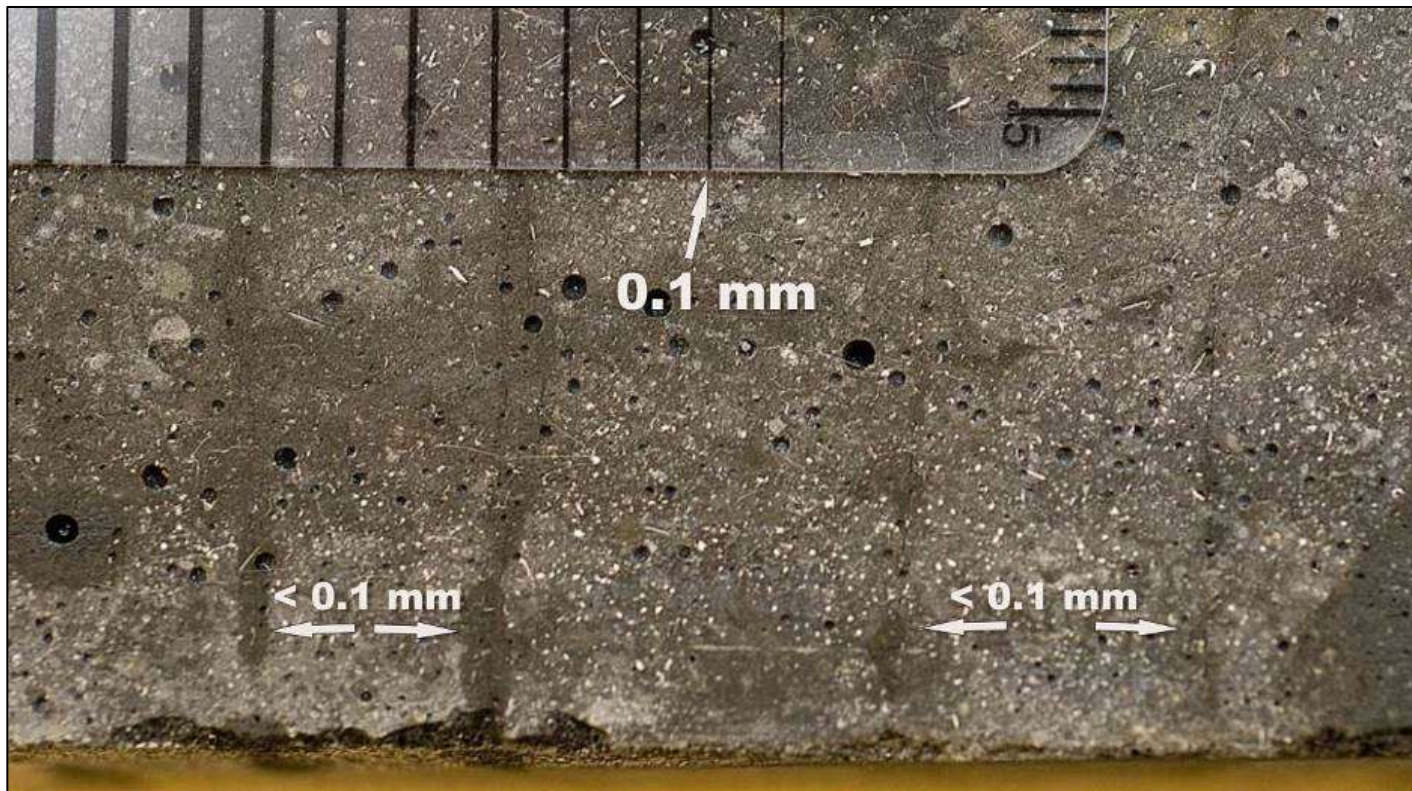
Flexural Strength



4-in-thick beams at 2 months

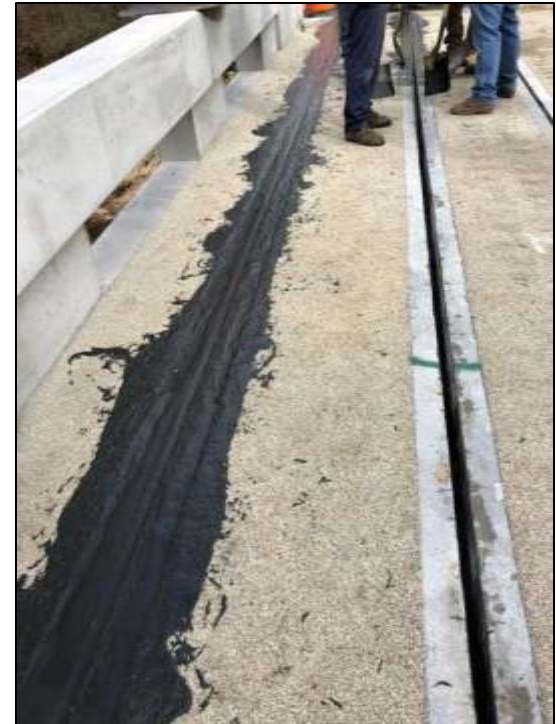


UHPC - Tight Cracks



1-in-thick beam

New UHPC - 2019

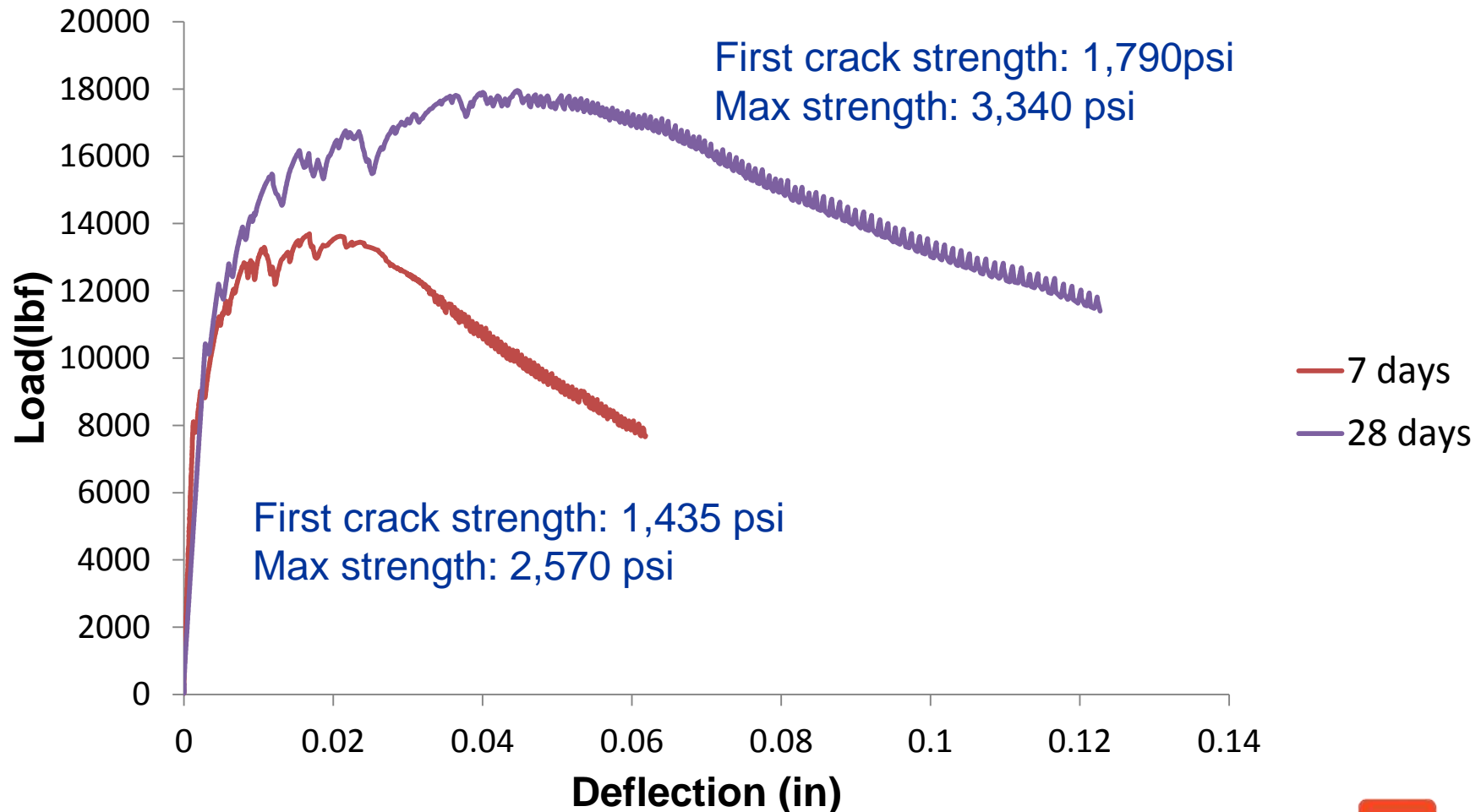


Planetary mixer

28-d compressive strength $\geq 17,000$ psi



Flexural Strength – New UHPC



Conclusion

- Fibers provide residual strength after cracking, which limits the size and length of cracks and can be used in shear keys, closure pours, block-outs, and culvert repairs.
- The level of residual strength depends on the type and amount of fibers.
- High residual strengths that exhibit strain and deflection hardening limit cracks widths below 0.1 mm.



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VTRC

Virginia Transportation
Research Council



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Thank You.

